

## Cyanobacterial species, potentially forming water-blooms in the Lake Titicaca (Peru)

## Especies cianobacteriales, formadoras potenciales de floraciones en el lago Titicaca (Perú)



*Haydée Montoya*

Laboratorio de Simbiosis Vegetal, Museo de Historia Natural, UNMSM,  
Av. Arenales 1256, Apartado 14-0434, Lima 14, Perú  
haydmon@yahoo.com

*Jarka Komárková & Jiří Komárek*

Institute of Botany, Academy of Sciences of the Czech Republic,  
Dukelská 135, Cz-37982 Třeboň, Czech Republic  
jiri.komarek@ibot.cas.cz; jarkakom@hbu.cas.cz



## Abstract

The Puno Bay on the large and known Lake Titicaca at the South Peruvian Andes of the South American was distinctly eutrophized in first years of the 21st century, owing to the influence from increasing and continual human settlement on the shore and touristic activities. The consequence of the eutrophication is the occurrence of the high production of cyanobacterial, macroscopic “water-blooms” in the bay. The commonly distributed and toxin producing species *Microcystis aeruginosa* is already fully developed, and the other potential water-blooms, forming by the species *Limnoraphis robusta* and *Nodularia inca* occur in littoral communities. The last from these species seems to be special and characteristic only for the Lake Titicaca. The suppression of the negative cyanobacterial developments in the lake is possible only after restriction of the input of vastest into the lake, and by the discreet regulation of human activities.

**Keywords:** cyanobacteria, water-blooms, lake Titicaca, Peru

## Resumen

La Bahía de Puno del gran Lago Titicaca en los Andes Peruanos del Sur en Sudamérica fue notoriamente eutrofizado en los primeros años de la 21va centuria a causa de la influencia de los incrementos continuos de establecimientos humanos en las orillas y las actividades turísticas. La consecuencia de la eutroficación es la presencia de una alta producción cianobacterial macroscópica de floraciones en la bahía. La especie *Microcystis aeruginosa* que es de distribución común y productora de toxinas está muy desarrollada y otras especies potenciales de floraciones esta dado por las especies *Limnoraphis robusta* y *Nodularia inca* que ocurren en las comunidades litorales. La última de las especies parece ser especial y característica solo para el lago Titicaca. La supresión del desarrollo de negativo cianobacterial en el lago es posible solo después de las restricciones en el ingreso de incesantes desechos en el lago y por una regulación de las actividades humanas.

**Palabras clave:** cyanobacteria, floraciones, lago Titicaca, Perú

## Introduction

Cyanobacterial water-blooms are indicators of increasing pollution of freshwater reservoirs (lakes, ponds) all over the world. Several common species participate in heavy water-bloom over many countries, but few special and interesting species appear in separated areas. Because the formation of cyanobacterial populations is connected in reservoirs with several, often negative ecological markers (mass production of biomass, enrichment of water by nitrogen, production of cyanotoxins, depletion of oxygen in water, changes of pH, the study of planktic cyanobacteria belongs to the prominent problems of the modern theoretical as well as applied hydrobiology.

In several large lakes in tropical and

subtropical zones of American continents appeared recently several characteristic species and developed water-blooms in such lakes and reservoirs, which had up to now more or less oligotrophic character. Commonly is here spread and distributed the almost cosmopolitan *Microcystis aeruginosa*, however, with increasing eutrophication several other species appear, from which few are newly discovered or little known. To the recently occurring dangerous species belongs, e.g., *Cylindrospermopsis raciborskii*, which was found expanding from tropical up to temperate zones in the second half of 20th century, also over both American continents (in South America, e.g., Cronberg 1978; Bonilla 2009). We describe in this article the present situation in the bay of Puno, Lake Titicaca, Peru, at the end of



the summer period 2013/2014, as concerns the potential cyanobacterial water-blooms, with the possible prognosis for the future.

### Methods

The material and plankton samples were collected during March 2014 from the Puno Bay of the Lake Titicaca, Peru (3800 m a.s.l.), by help of the plankton net with the diameter of openings of 10µm, and by the direct collection of samples from the littoral (with dominating macrophyte *Schoenoplectus californicus*). The main hydrobiological parameters of the Lake Titicaca are published, e.g., in Dejoux & Iltis (1991), the water temperature was between 10 and 20°C, and the pH was from 8 to 9.

The planktic community was studied by microscopes Olympus BX 51 and Leitz Dialux 22, and documented by micrometer measurements, drawings and microphotos.

In the community of phytoplankton was dominant *Elakotothrix* sp., *Pediastrum boryanum* and the dinoflagellate *Ceratium hirundinella*. Less biomass was produced by few other species of green coccoid algae.

### Results and discussion

About the lake Titicaca were published already numerous informations. The most important belong to the limnologically oriented papers of Richerson *et al.* (1977; 1986) and Dejoux & Iltis (1991). However, these publications are already old and the situation in the lake was recently substantially changed. The increased human population around the lake and the tourism are evidently the certain phenomena, leading to the negative increase of eutrophication of this extremely interesting and valuable lake.

In the Puno bay of the Lake Titicaca were registered recently three planktic

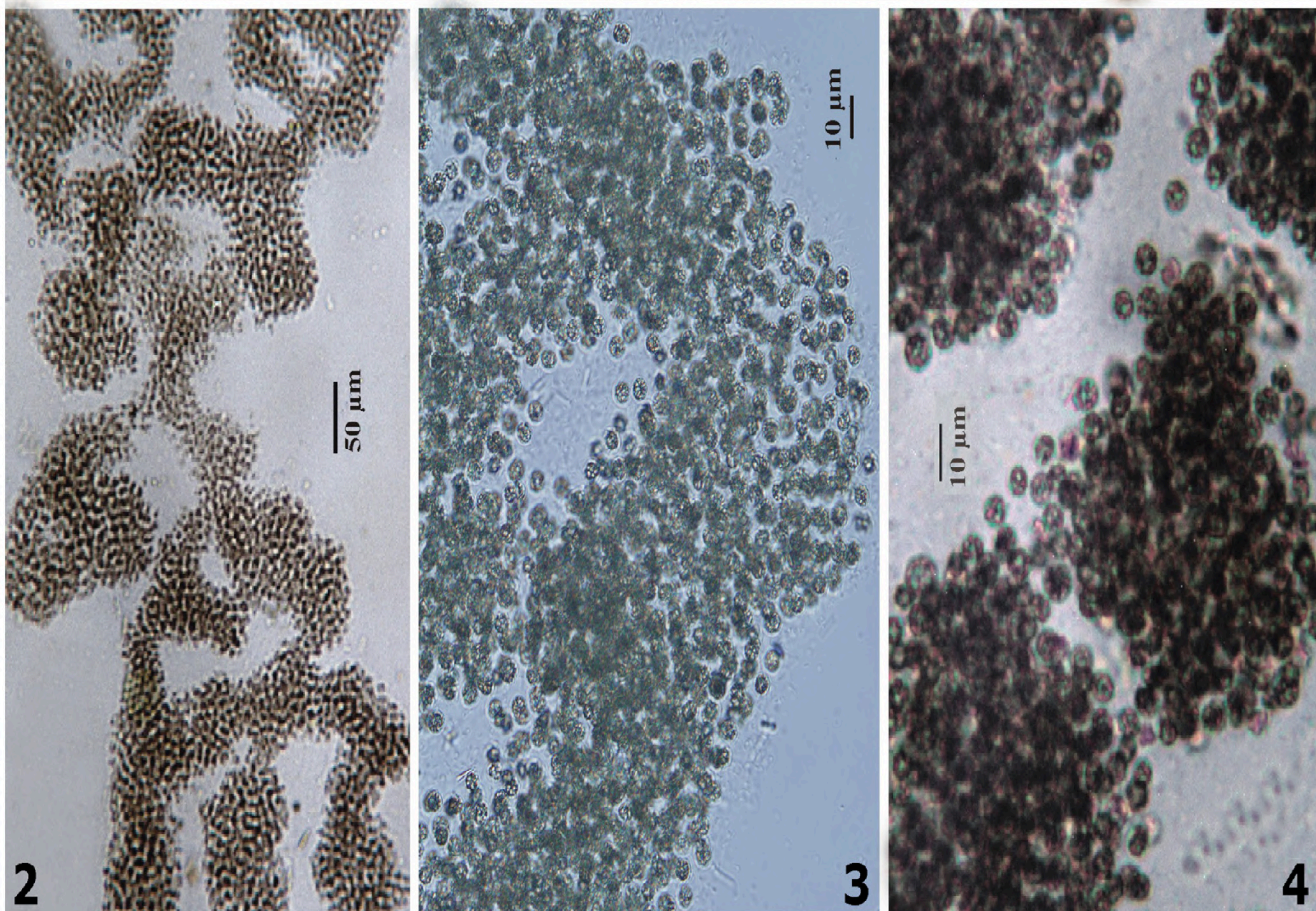
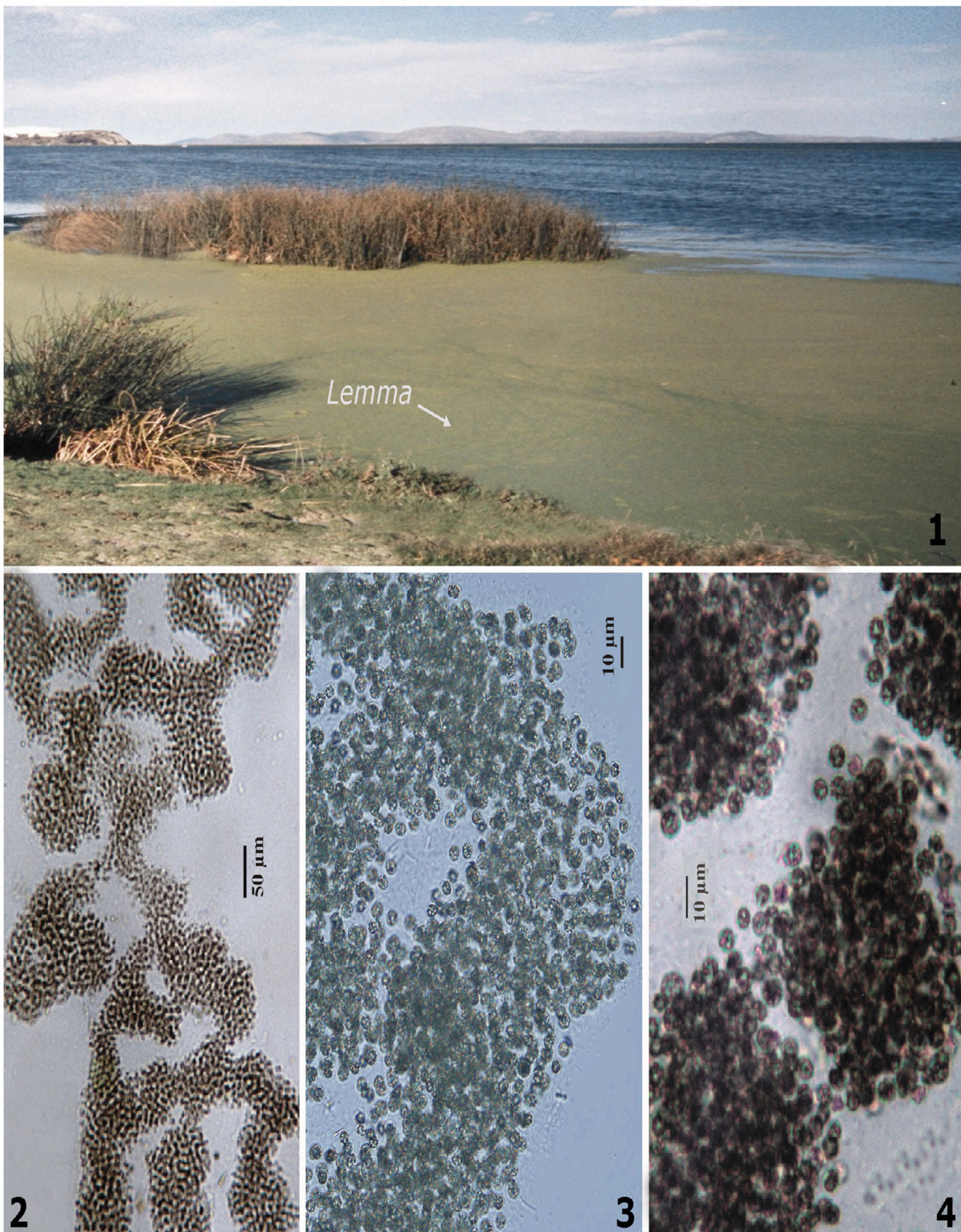
cyanobacteria with aerotopes in cells, which can form potentially important water blooms and can be prominent in plankton with increasing eutrophication. Richerson *et al.* (1977) reported the planktic centric diatom *Stephanodiscus astrea* as dominant in dry season, accompanied mainly by “green and blue-green species”. This situation resembles the mesotrophic character of the lake. Besides, this character was supported by Carney *et al.* (1987), they established the meso-oligotrophic character for the epilimnetic phytoplankton. However, the newly registered cyanobacterial species (particularly *Microcystis aeruginosa*) are indicators of the worsen situation of the lake. The registered cyanobacterial taxa can cause dangerous changes (change of the ecosystem), connected with increasing input of nutrients, or with non-regulated management of the water lake and reservoirs.

The following planktic cyanobacteria are reported for the Titicaca Lake

#### *Microcystis aeruginosa* (Figs. 2 - 4)

*M. aeruginosa* was not mentioned by previous authors, but it forms already relatively dense water-blooms, agglomerated near the water level in stable periods (without wind) in Puno Bay. The population forms the macroscopically visible, floating, typical colonies. The water-bloom is spread in the whole water column in windy periods of the day (usually in the afternoon), and in this time disappears apparently from the surface. The *Microcystis* population of Titicaca lake corresponds morphologically to other similar populations of this species from western coasts of American continents, and evidently belongs to the cosmopolitan *Microcystis aeruginosa* genome, described by van Gremberghe *et al.* (2011). *M. aeruginosa*





**Fig. 1.** Development of *Lemna* population in littoral parts of Titicaca Lake (Puno Bay). The population is agglomerated near the shore under influence of wind. The colonies of the water bloom forming cyanobacterium *Microcystis aeruginosa* are spread in the lake water.

**Figs. 2-4.** *Microcystis aeruginosa*, population from Puno Bay, Titicaca Lake.



belongs to the most dangerous water-bloom forming cyanobacterial species in respect to its production of toxin compounds and high production of macroscopic biomass, following the drastically increasing eutrophication and eliminating the sensitive members (species) from oligotrophic biocenoses in aquatic ecosystems.

In the Puno bay the *Microcystis* population is already fully developed and combined with another indication of the strong pollutants in the water, *Lemna* sp., covering in several areas the water surface by a continual layer. The prevention of further development of this community (combined vegetation of *Lemna* with *Microcystis*) is possible only by elimination of the pollution of the lake, by total restriction of the input of wastes from the increasing human populations on the shores, regulation of the increasing touristic activity of Puno (waste control), and perhaps also with the mechanic collection and removing of organic material (cyanobacteria, *Lemna*) floating on the water level in some year periods.

#### *Limnoraphis robusta* (Figs. 5-8)

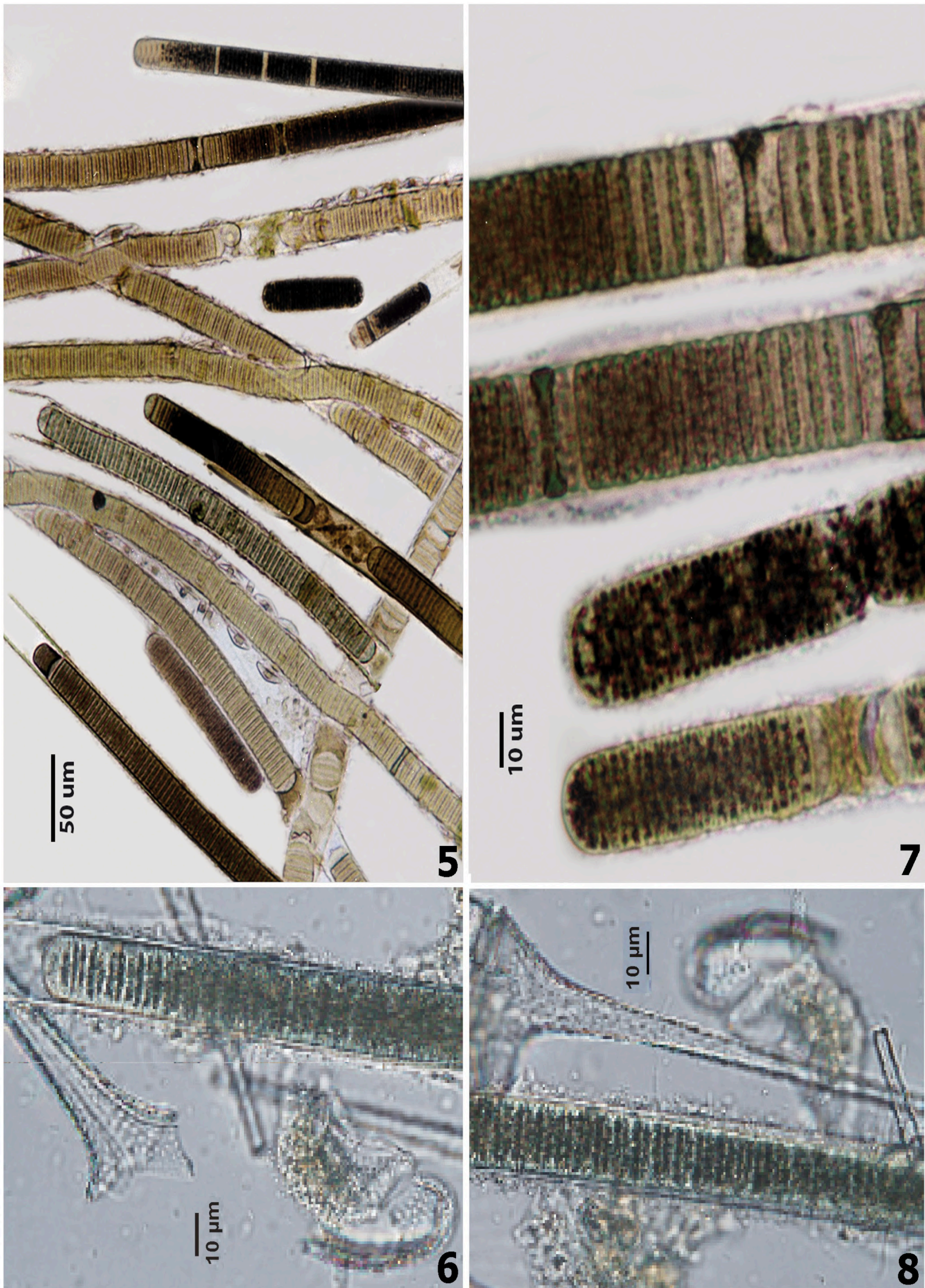
*L. robusta* (syn. *Lyngbya hieronymusii* var. *robusta*) is a tropical, filamentous, relatively large (almost 20 µm wide filaments), planktic, not branched, non-heterocytous cyanobacterial species with gas vesicles in cells. This species started recently (in last ten years) to form periodical and heavy water blooms in water reservoirs on the western parts of a tropical zone of American continents. The relatively small aerotopes are distributed within the cells volume in segments of majority of filaments, and the species contains high amount of various carotenoids, causing the yellow-brown coloration of the massive water-bloom of this species. This cyanobacterium was not known as a water-bloom forming

species up to the beginning of the 21<sup>st</sup> century and occurred only sporadically in tropical unpolluted reservoirs. After 2005 appeared mass production of this species in several large reservoirs, usually as a result of the higher input of phosphorus into the oligotrophic tropical and subtropical lakes. Such water-blooms were described particularly from the large and deep volcanic lake Atitlán in Guatemala (Rejmánková *et al.*, 2011; Komárek *et al.*, 2013) and from the Clear Lake and the Sacramento-San Joaquin Delta of South California (Mioni *et al.*, 2011/2012). In these populations were not detected tox-genes and the cyanotoxicity was not confirmed, but it was proved the intense nitrogen fixation under anaerobic conditions (in night), which causes the increase of suitable conditions for other, possibly toxic cyanobacteria (it is already the case of Atitlán Lake in Guatemala).

In March 2014, *L. robusta* was found as the common additional species in littoral of the floating islands in Titicaca lake with the dominant *Schoenoplectus californicus* “junco” “totora”. The presence of *Limnoraphis* represents a risk of its potential biomass developments. In comparison with the known “water-blooms” of this species, the situation in the lake can be positive for its mass development, particularly when the phosphates from wastes will increase in the water. The biomass production of *Limnoraphis* is a negative phenomenon particularly for touristic activities (repugnant appearance of the yellow-brown water-bloom), and for the change of ecological conditions in water, but its regulation and control is easier than the toxic and more dangerous members of the cyanobacteria genera *Aphanizomenon*, *Dolichospermum* or *Microcystis*.

In previous papers was mentioned from Titicacalake only “*Lyngbya vacuolifera*” Skuja.





Figs. 5-8. *Limnoraphis robusta*, solitary filaments with distinct segments with aerotopes in cells.



However, it is quite different species (Skuja, 1948), more related to the genus *Limnothrix*. It was described from Scandinavia and occurs only in Nordic regions of temperate zone (northern Europe, Canada) (Komárek & Anagnostidis, 2005). The morphology is quite different from *Limnoraphis robusta*, its occurrence in the Puno Bay of the Lake Titicaca is questionable and should be confirmed. *Limnoraphis robusta* is morphologically more similar to the species *Lyngbya aestuarii*, also cited (but probably wrongly identified) from the Lake Titicaca. This species is typical for marine littoral (benthic) with high salinity, always without gas vesicles and its development in Titicaca Lake is ecologically almost impossible.

#### *Nodularia inca* (Figs. 9-12)

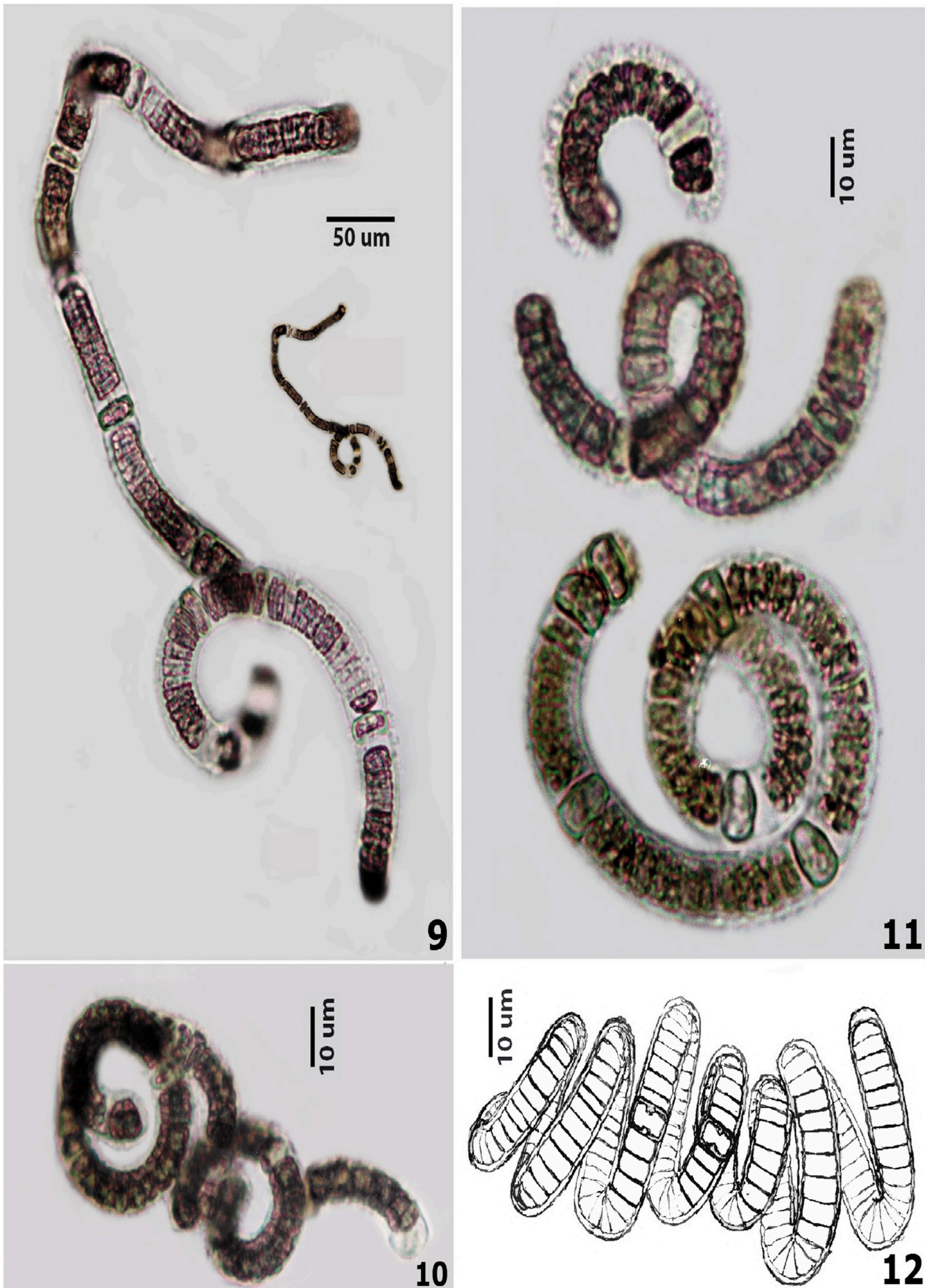
In the littoral samples of the floating islands of *Schoenoplectus californicus* was found a special type of planktic or metaphytic cyanobacterium, corresponding morphologically to the heterocytous genus *Nodularia*, at the end of the summer season 2014. This genus comprises several planktic species, known as the intense water-bloom forming types (Komárek, 2013). They contain gas vesicles in cells and up to now occurred mostly in slightly salinic, brackish or volcanic waters. The most known cases are the *Nodularia* water-blooms from Baltic Sea (Hübel & Hübel, 1980; Šmarda *et al.*, 1988; Komárek *et al.*, 1993; Hayes & Barker, 1997), SW Australia (Blackburn & Jones, 1995) and from the Caspian Sea (Proškina-Lavrenko & Makarova, 1968). They were described also from both American continents (Nordin & Stein, 1980, Galat *et al.*, 1990, Alvarez & Bazán, 1994; Tavera & Komárek, 1996; Perez *et al.*, 1999). The *Nodularia* populations from Titicaca Lake have a characteristic morphology (irregularly coiled, solitary trichomes with aerotopes in cells) and does not correspond

to any up to now known planktic species. Screw-like coiled trichomes are known only in *Nodularia spumigena* from marine Baltic halophilic populations. The special toxin nodularin was detected in the water-bloom forming species of this genus, but it must be confirmed also in Titicaca populations.

The population from the Lake Titicaca is evidently adapted to the planktic mode of life and can be potentially invasive species under certain conditions. It is evidently the unknown *Nodularia*-taxon yet. Only *Nodularia harveyana* is cited from Titicaca in previous papers (Richerson *et al.*, 1977; 1986). This halophilic species is, however, without aerotopes and has different morphology from the present Titicaca populations. Particularly the coiled trichomes are characteristic for Titicaca specimens. Maybe that previous authors misinterpreted this species as *Anabaena spiralis* (Richerson *et al.*, 1977), but the occurrence of this species is also questionable in Titicaca: the screw-like morphology of this taxon is different type, while our material has all characters of the genus *Nodularia*, different from all planktic *Anabaena* or *Dolichospermum* (= planktic "*Anabaena*") species. Also the cited *Anabaena sphaerica* from Titicaca plankton is improbable. This taxon occurs in soils and maybe found in benthos and littoral, but never in plankton and never forming gas vesicles.

The modern taxonomy of cyanobacteria is based mostly on the polyphasic evaluation including the molecular analyses, but we were not yet able to transfer this species into the culture. In spite of it, we describe this taxon as a new species on the basis of special morphology and ecology. It is evidently morphologically and ecologically different from all up to now described *Nodularia*-species and we suppose its definition as necessary in the respect to the ecological





**Figs. 9-12.** *Nodularia inca*, variability in coiling of solitary filaments. The aerotopes seem to be irregularly distributed in segments of trichomes.



situation in Titicaca Lake. The description of this species is as follows:

*Nodularia inca* spec. nova – Filaments solitary, irregularly coiled, rarely only flexuous, up to shortly and densely screw-like contorted, 7-8 µm wide. Trichomes cylindrical, slightly constricted at cross walls, enveloped by thin, colourless and often indistinct envelope. Cells always shorter than wide, usually 2.5-3 µm long, with granular content and small, blackish, point-like, aerotope-like inclusions; end cells widely rounded. Heterocytes rectangular with rounded ends, ± hyaline, intercalar and solitary, rarely in terminal position, 3.5-5 x ±8 µm, in terminal position slightly longer. Akinetes not observed, but all morphological characters corresponded to the planktic specimens of the genus *Nodularia*. Reproduction by short hormogonia. Habitat: Planktic and metaphytic in littoral of floating islands in Puno Bay, Titicaca Lake, Peru. - Type: Figs. 10 -12 - Etymology: The species is named to the honor of the original inhabitants of the vicinity of the Lake Titicaca.

### Conclusions

- The trophic level of the lake Titicaca (particularly in Puno Bay, Peruvian Andes) changed from the oligotrophic to mesotrophic type in last years.

- The higher trophic level in the Puno Bay caused the temporary massive development of cyanobacterial water-blooms, formed by toxin producing species *Microcystis aeruginosa*, which forms here the characteristic community with the pleustonic *Lemna* sp.

- In the wide littoral (mostly among *Schoenoplectus californicus*) occur the other filamentous cyanobacteria with gas vesicles (and aerotopes) in cells, which can

represent potential danger of their intense development in continually eutrophized bay of the lake.

- One of these species, *Limnographis robusta*, is known from last 10-15 years as a water-bloom forming and N-fixing cyanobacterial species from large lakes of western tropical and subtropical parts of American continents.

- The second potentially water-bloom forming filamentous species was described as a new taxon from littoral of the lake (*Nodularia inca*), with irregularly screw-like coiled filaments.

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